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Short communication

Fractions of soil phosphorus under maize–blackgram-groundnut cropping sequence

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Despite its wide distribution in nature, P is a limited resource for plant growth and its low availability is a major constraint to crop production in most arable soils. The contents of different phosphorus (P) fractions in soil depend upon various factors such as texture, organic carbon, calcium carbonate, water regimes, soil pH and type and amount of phosphatic fertilizers given to the crop plants. Besides these factors, distribution and content of P fractions is also affected by different cropping patterns followed in a particular area. Duration of crop also affects the forms of soil phosphorus to a considerable extent (Aggarwal *et al.,* 1987). The full phosphorus dosage (P_2O_5) should be applied during sowing because phosphorus demand is highest in the initial stages of crop growth. The phosphate applied to the soil undergoes complex reactions (transformations) with various components like Fe, Al, Mg, Ca, clay minerals, rapidly converting into less soluble or insoluble forms. About 20 to 25 percent of the phosphatic fertilizer applied is utilized by the crop, while the remainder turns into insoluble phosphorus forms, becoming fixed in the soil. Insoluble phosphorus forms can't be taken up by crops directly; they need to be converted into soluble forms by enzymes like acidic and alkaline phosphatase. Certain soil microorganisms, particularly phosphate solubilizing bacteria (phosphobacteria), possess the capability to make insoluble inorganic phosphate soluble for plant uptake. This solubilization effect is generally due to the production of organic acids by these organisms, and it indirectly but significantly influences nodulation and yield of legume crops like groundnut by increasing phosphate solubilisation. Interpretations on temporal variation in various fractions of P as affected by INM under maize based cropping sequence with the inclusion of a summer legume are finite in *Alfisols*. Henceforth, the current study is propounded with the goals to pinpoint the role of fractions of P in the nutrition of constituent crops. Field experiments were carried out during *rabi, summer* and *kharif* seasons of 2019-20 at S.V. Agricultural Farm, Tirupati, Andhra Pradesh. Maize was sown in *rabi* season as main plot treatments replicated three times in randomized block design. Maize hybrid 'Pioneer 3396' was sown on 25th November, 2019 and harvested on march,12 2020. Blackgram variety 'TBG-104' was grown as residual crop sown after harvest of maize on March 29,2020 and was allowed to grow till maturity. After two pickings, the stover was incorporated into the soil on June 11, 2020. Groundnut variety 'Dharani' was sown on July 1, 2020 and harvested on October 23, 2020. Standard package of practices were followed for all the three crops. Phosphorus and potassium were applied as basal whereas nitrogen was applied in three splits, *viz*., before sowing, at knee high stage and before silking stages. FYM was incorporated before sowing of maize. Upon reviewing the data (Table 1), it is evident that there was a consistent rise in both the inorganic and Olsen P levels within the soil, from the sowing to the silking stage of maize. This can be attributed to the reduction in extractable organic P due to mineralization (Mamathashree *et al.,* 2018), causing the release of P into the solution and leading to an increase in inorganic P content. This increase was more pronounced in treatments receiving higher doses of P, a trend similarly observed by Sunitha and Singh (2016). The increase in Olsen P was observed across all treatments, including the control, and could be linked to the higher soil-P dissolution facilitated by root exudates. Then followed the statistically similar treatments T_4 (36 mg kg^{-1} soil), T_5 (33.5 mg kg^{-1} soil) and T_6 (32 mg kg^{-1} soil). The lowest value of Olsen P was obtained under T_1 (30.2 mg kg^{-1} soil) followed by T_2 (31 mg kg^{-1} soil). This shows that application of no or low amount of P fertilizer was unable to maintain high amounts of available P in soil. The treatment T_9 recorded the highest amount of 0.5M $NaHCO_3$-extractable P (Olsen P) with a value of 40.5 mg kg^{-1} soil.

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Table 1: Distribution of Soil P fractions under maize-blackgram-groundnut cropping sequence

	Maize (Silking Stage)					Blackgram (Flowering Stage)					Groundnut (Flowering Stage)				
Treatments	Olsen P	LB-P	Al-P	Fe-P	Ca-P	Olsen P	LB-P	Al-P	Fe-P	Ca-P	Olsen P	LB-P	Al-P	Fe-P	Ca-P
T_1: Control	30.2^{e}	11.5^{d}	25.5^{c}	25.8^{ab}	22.0^{e}	23.6^{d}	6.5^{f}	24.2^{f}	23.6^{b}	33.7^{c}	18.0^{c}	6.99^{b}	23.0^{d}	29.2^{bc}	51.2^{c}
T_2: FYM @5 tha^{-1}	31.0^{e}	12.6^{cd}	25.3^{c}	27.6^{bc}	36.5^{e}	27.0^{c}	8.0^{ef}	26.0^{ef}	27.5^{a}	47.2^{ab}	20.1^{bc}	7.23^{b}	24.5^{cd}	28.4^{c}	56.5^{ab}
T_3 : 100% RDF	38.4^{ab}	17.7^{a}	40.5^{a}	29.3^{ab}	46.3^{a}	37.6^{a}	17.6^{a}	38.2^{ab}	28.0^{a}	53.0^{a}	23.1^{a}	10.02^{a}	31.0^{a}	32.1^{a}	57.0^{a}
T_4 : 75% RDF	36.0^{bcd}	15.0^{b}	31.0^{b}	27.5^{bc}	38.6^{c}	34.1^{b}	13.0^{bcb}	26.4^{ef}	27.1^{a}	50.3^{ab}	23.4a	9.62^{a}	28.0^{abc}	28.6^{c}	51.5^{c}
T_5 : 50% RDF	33.5^{cde}	14.9^{b}	30.5^{b}	27.5^{bc}	37.0^{c}	33.5^{b}	10.5^{de}	27.1^{ef}	27.7^{a}	44.5^{b}	22.3^{ab}	9.53^{a}	27.2^{bc}	29.0^{c}	52.4^{c}
T_6 : 100% RDN	32.0^{de}	11.8^{d}	25.1^{c}	28.5^{ab}	30.0^{d}	24.5^{d}	8.0^{ef}	29.0^{de}	28.5^{a}	34.0^{c}	20.0^{bc}	8.00^{b}	23.5^{d}	28.0^{c}	44.2^{d}
T_7 : 100 % RDP	37.0^{dbc}	17.5^{a}	31.5^{b}	30.6^{a}	37.0^{c}	35.2^{b}	17.5^{a}	35.2^{bc}	29.0^{a}	36.2^{c}	22.4^{ab}	9.51^{a}	29.4^{ab}	31.3^{ab}	51.5^{c}
T_8 : 100 % RDF + FYM @5 t ha^{-1}	37.3^{abc}	13.8^{bc}	38.3^{a}	27.0^{bc}	42.3^{b}	33.5^{b}	15.0^{abc}	39.5^{a}	28.5^{a}	52.4^{a}	23.0^{a}	9.48^{a}	31.0^{a}	30.5^{abc}	52.0^{c}
T_9 : 75% RDF + FYM @5 t ha^{-1}	40.5^{a}	14.0^{bc}	39.5^{a}	27.8^{bc}	43.2^{ab}	34.1^{b}	15.7^{ab}	41.2^{a}	29.5^{a}	53.2^{a}	23.5^{a}	10.02^{a}	31.5^{a}	30.5^{abc}	53.2^{bc}
T_{10} : 50% RDF + FYM @5 t ha^{-1}	37.3^{abc}	15.2^{b}	28.6^{bc}	27.0^{bc}	36.8^{c}	33.5^{b}	12.0^{cd}	32.0^{cd}	29.9^{a}	46.6^{ab}	22.6^{ab}	9.38^{a}	31.0^{a}	30.0^{abc}	45.0^{d}
Mean	35.3	14.4	31.6	27.9	37.0	31.6	12.4	31.9	27.9	45.1	22.0	9.0	28.0	30.0	51.0
SEm ±	1.43	0.50	1.50	0.80	1.23	0.67	1.01	1.15	1.03	2.42	0.949	0.372	1.220	0.880	1.130
CD (P=0.05)	4.28	1.49	4.50	2.41	3.69	2.00	3.02	3.45	3.10	7.25	2.82	1.11	3.63	2.62	3.36
Sub plots															
S_1 : Control											19.7^{c}	7.90^{c}	23.8^{c}	26.7^{c}	49.3^{c}
S_2 : 75% RDF											24.0^{a}	10.32^{a}	32.3^{a}	32.8^{a}	54.2^{a}
S_3 : 50% RDF											21.8^{b}	8.72^{b}	27.8^{b}	29.8^{b}	50.9^{b}
SEm+											0.223	0.138	0.324	0.223	0.264
CD (P=0.05)											0.64	0.39	0.93	0.64	0.76
Interaction															
S at T															
SEm+											0.704	0.436	1.024	0.705	0.835
CD (P=0.05)											NS	NS	2.93	2.01	NS
T at S															
SEm+											1.403	0.584	1.824	1.310	1.669
CD (P=0.05)											NS	NS	5.24	3.77	NS

The inclusion of blackgram in the system acted as a buffer against the decline in Olsen P values in treatments previously subjected to higher (> 75%) recommended fertilizer P doses. Nonetheless, this decline couldn't be prevented in other treatment cases. As a leguminous crop, blackgram releases specific organic acids into the soil through its roots, enhancing native phosphate dissolution. This could potentially explain the relatively stable Olsen P values in the soil, even without external phosphorus application to the crop. The order in which the treatments influenced the Olsen P content of the soil at flowering stage of blackgram was: T_3 (37.6 mg kg^{-l} soil) > T_7 (35.2 mg kg^{-1} soil) > T_9,T_4 (34.1 mg kg^{-1} soil) > T_5,T_8,T_{10} (33.5 mg kg^{-1} soil) > T_2 (27 mg kg^{-1} soil) > T_6 (24.5 mg kg^{-1} soil) > T_1 (23.6 mg kg^{-1} soil). The Olsen P content of the soil further decreased before incorporation of blackgram, this stresses the necessity for continuous P fertilizer application to the crops in a cropping system. Tarik *et al*. (2016) have also raised this point earlier. After sowing of groundnut, the Olsen P gradually declined up to groundnut harvest. This again could be due to crop uptake and P fixation.

The inorganic P fractions within the soil exhibited an increase from the sowing to the silking stage of maize. This corresponded with the rise in inorganic P content following the addition of phosphatic fertilizers and farmyard manure (FYM). The beneficial impact of phosphatic fertilizers on various soil P fractions has been documented by Haokip *et al*. (2019). Furthermore, the augmentation of P fractions was directly related to the quantity of P introduced through fertilizers, as noted by Nayak and Patel in 2016. The highest loosely bound-P (LB-P) content was observed under treatment T_3 (17.7 mg kg^{-1} soil), followed by T_7 (17.5 mg kg^{-1} soil). The soil's highest iron-P (Fe-P) content was maintained under T_7 (30.6 mg kg^{-1} soil), on par with T_3 (29.3 mg kg^{-1} soil) and T_6 (28.5 mg kg^{-1} soil).

Comparatively lower LB-P contents were sustained under T_1 (11.5 mg kg^{-1} soil), T_6 (11.8 mg kg^{-1} soil), and T_2 (12.6 mg kg^{-1} soil), which also accounted for the lower levels of aluminum-P, with the highest under T_3 (405 mg kg^{-1} soil). The most significant LB-P content was maintained under T_3 (17.6 mg kg^{-1} soil), and values for different inorganic P fractions were found to remain unchanged from the flowering stage of blackgram to the stage prior to its incorporation, i.e., maturity. This could be attributed to the absence of P fertilizer application after the maize crop and the distribution of soil P among various reservoirs. Furthermore, P uptake by blackgram would likely have been nearly complete by this stage.

Conversely, the lowest LB-P content was noted under T_1 (6.5 mg kg^{-1} soil), on par with T_2 and T_6 (8.0 mg kg^{-1} soil). T_1 (23.6 mg kg^{-1} soil) exhibited significantly lower Fe-P content compared to other treatments. Treatment T_1 maintained the lowest Al-P content (24.2 mg kg^{-1} soil) compared to the rest, while the highest Al-P amount was recorded under T_9 (41.2 mg kg^{-1} soil). The proportions of Al-P, Fe-P, and LB-P to the total inorganic P were approximately 8-12%, 6-8%, and 1-3%, respectively. Numerous researchers have reported the predominance of Ca-P in neutral to alkaline soils (Jayshive *et al.,* 2019). These findings concerning various inorganic fractions imply their interdependence, where an increase in one fraction triggers a decrease in another. Moreover, these fractions are affected by the amount of P fertilizers added to the soil. Ca-P emerged as the dominant fraction in the experimental soil, constituting 50 to 55% of inorganic P.

It's important to note that fertilizer P was applied to all plots except S prior to groundnut sowing. This resulted in higher LB-P, Fe-P, and Al-P amounts in the soil during the flowering stage compared to the earlier stage. This increase was more pronounced in plots that had received higher P doses during the maize phase. The addition of soluble P fertilizer is known to convert Ca-P into LB-P, Fe-P, Al-P, and Occ-P fractions in the soil (Venugopal *et al.,* 2017; Swetha *et al.,* 2018). The calcium P content steadily increased from groundnut sowing to harvest, likely due to the conversion of a portion of LB-P, Al-P, and Fe-P to the more resistant Ca-P as the crop matured and its P requirements were fulfilled. The impact of soluble phosphorus (P) fertilizers on diverse phosphorus fractions within the soil, along with their behavior during different crop growth stages, has been explored in prior studies. Notably, the work of Jakasaniya and Trivedi (2004) revealed that the introduction of soluble P fertilizers led to an increase in the prevalence of labile-P (LB-P) and aluminum-bound P (Al-P) in the soil. Verma *et al*. (2005), on the other hand, posited that the initial phases of crop growth triggered a transformation of calcium-bound P (Ca-P) into Al-P and iron-bound P (Fe-P), with this trend reversing as the crop reached maturity. It was further observed that the utilization of water and citrate soluble P fertilizers resulted in a relatively more pronounced augmentation of LB-P, Al-P, and Fe-P fractions compared to calcium-bound P (Ca-P). The trajectory of phosphorus fractions throughout distinct crop growth stages revealed intriguing patterns. Following the silking stage of maize, a decline in LB-P fraction was noted, likely attributable to its conversion into more resilient phosphorus compounds. This reduction persisted until just before the sowing of groundnut. Subsequent to the incorporation of blackgram, a substantial decrease in LB-P and Al-P was observed, likely a consequence of phosphorus immobilization facilitated by microorganisms. During the flowering phase of groundnut, resurgence in LB-P, Fe-P, and Al-P content was witnessed, linked to both the application of P fertilizer to the groundnut crop and the liberation of P from residual blackgram matter.

Based on the preceding paragraphs, it's evident that LB-P and Al-P represent the fractions responsive to external fertilizer application, signifying their immediate equilibrium with plant-accessible P. As the crop matures, these fractions transition into Ca-P, which becomes the predominant and most resilient fraction. When needed, Ca-P transforms back into Al-P and LB-P to release P for crop growth. Therefore, it's crucial to focus more on these three fractions for a more insightful understanding of P dynamics in this soil. While Fe-P can also undergo changes due to external fertilizers, as reported by some researchers, its content in relation to total inorganic P remained relatively stable throughout the experimental period. Nevertheless, to validate these findings and establish indicators of P availability among the various P fractions, this experiment should be extended for a longer duration.

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